DEVELOPMENT OF COMPOSITE PROGRESSING CAVITY PUMPS

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ABSTRACT

The newest technological advancement in the Progressing Cavity Pump (PCP) industry has been the development of composite stators and rotors. Included in this design concept is a reversing of the conventional elastomer and hard surface interface. The stator, in this design concept, is made of a hard composite material and is placed in a steel tube jacket. The rotor can be made of steel or composite material and coated with an even thickness of a soft and durable polyurethane. The urethane offers increased wear resistance and mechanical properties over conventional elastomers and the even thickness offers additional performance enhancements. Also, the elastomeric placed on the rotor offers the well-servicing advantages of the wear element being located on the end of the sucker rod string rather than on the end of the tubing string. The composite PCP becomes a low cost, highly durable PCP that incorporates the emerging even thickness elastomer technology.

INTRODUCTION

Until recently, the Progressing Cavity Pump (PCP) most widely used in down-hole conditions consisted of a stator made of a nitrile based elastomer that is injected and permanently bonded inside a steel tube, and a rotor, machined from steel and coated with a relatively thick layer of chrome plate. Both the stator and rotor are helical where the stator always has one more helix than the rotor. In this configuration the stator is the wear section and the rotor is the longer wearing element. In the most widely used design the elastomer in the stator has consistent thick and thin sections corresponding to the major and minor diameters of the stator bore. This variance in elastomer thickness leads to difficulties optimizing performance due to swell resulting from incompatibility with well fluids and thermal expansion resulting from elevated well bore temperatures plus heat generated by internal friction in the pump. For some time now the industry has been seeking a cost effective approach to this inherent design problem and have made some advancements in “even wall” or “even thickness” elastomer stators. The even thickness elastomer optimizes performance with respect to swell and thermal expansion plus offers additional performance enhancements with respect to operating efficiencies.

Another inherent design problem is that the stator is located on the bottom end of the production tubing string and the rotor is located on the bottom end of the sucker rod string. As the stator wears or fails and pump performance deteriorates to a point the pump requires service, the rod string and rotor are pulled from the well, then the production tubing string and stator are also pulled from the well. The need to pull tubing each time the pump requires service is a major drawback in using PCP’s in most applications.

The newest technological advancement that addresses the problems normally associated with PCP’s; elastomer incompatibility and/or wear, changing stator geometry under operating conditions, and lengthylcostly well service is currently in the early stages of development. In this new configuration, the stator is made of a hard composite material bonded to the inside of a steel tube. The composite material offers wear characteristics similar to or better than metal and makes the stator the longer lasting element. The rotor is made of steel or composite and coated with an even thickness of soft and durable polyurethane (PU). The polyurethane offers increased wear resistance and mechanical properties over conventional nitrile elastomers in the same applications. The requirement of pulling tubing each time the pump requires service is eliminated with the placement of the elastomer on the rotor.

COMPOSITE STATORS

In the search for ways to line the stators with an even thickness layer of elastomer alternate methods of creating an internal double helix steel tube have been developed. These processes include forming the tube to the complex shape or machining the shape inside a hollow bored steel bar. Stators have been developed using these methods and even layers of elastomer have been injected and bonded to the stator walls. The testing of this configuration indicates significant increases in mechanical efficiencies over the conventional configuration (non-uniform elastomer layer). The pressure

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developed by the same length seal and similar rotor/stator interference of the even thickness on average was found to be at least twice that of the conventional non-uniform layer. The problem remained that both processes of making the stator are expensive and normally do not yield consistently accurate parts. Having proven the mechanical superiority of the even thickness elastomer it was clear that a lower cost method of manufacturing the stator must be determined.

Composite technology has only recently become a viable means of part fabrication. Composites have been used in the automotive and aerospace industries for years and have only recently been used in the oil industry mainly in offshore applications. The composites used in the development of Progressing Cavity Pumps (PCP's) indicated in this paper are a combination of a reinforcement fiber in a polymer resin matrix where the fibers are thermally bonded to the resin matrix. The concentration of the reinforcement fibers allow for a transfer of loads between the fibers. The synergy created by load transfer between fibers, and the bonding of the reinforcement to the matrix determine the physical properties of the composite.

The process of making the stator is known as Resin Transfer Molding (RTM). The RTM process allows for various combinations of the resin matrix and reinforcing fibers and the development of composite materials that have controllable mechanical and physical properties. The composite formulation used for the stators have all the mechanical properties of steel with the added advantage of corrosion resistance. The advantages of a properly designed RTM process include the repeatability of parts with a better dimensional tolerance. If the tooling or cores used in the process are accurate then the finished part will be as accurate. The process yields either an exact replica of the tooling or it yields a scrap part. The exact replica of the tooling and the repeatability of this high level of dimensional tolerance plays a significant role in the increased mechanical operating efficiency of this pump configuration.

POLYURETHANE ELASTOMERS

Polyurethane (PU) or Urethane are terms used to categorize a group of elastomers or 'artificial rubbers' developed in the 1940's. Polyurethane elastomers combine the advantages of rigid plastics, metals and ceramics with the flexibility and elasticity of rubber. The molding of PU can yield a combination of the following physical properties:

- Excellent Resilience (high or low)
- Extra Toughness and Durability
- Very high load bearing capacity
- High Tear Strength and Cut Resistance
- Low Compression Set
- Very good impact resistance
- Outstanding Abrasion resistance
- Good mach inability
- Oil, solvent, water and ozone resistance.
- Non-marking
- Mold, mildew, fungus resistance
- Flex fatigue resistance
- Good Electrical properties
- Friction (high or low) Mechanical Properties

Polyurethane can be formulated to have a combination of many of these listed properties in one material. Many of these property combinations cannot be achieved in any other engineered product. So, a properly engineered compound can outlast an identical hardness part by a factor of several times.

Abrasion resistance is one property that is most recognized with PU. Increased abrasion resistance has been noted in many applications and PUs have outlasted both rubber and plastics in the same applications by factor as high as 8 to 1.

The toughness and durability of PU is noted in its stress/strain properties that can include a high modulus, high tensile strength and high elongation. This combination is not found in most rubbers. Rubbers normally have high elongation but low modulus and tensile strength. **Fig. 2.** Polyurethanes have much higher load-bearing capacity than conventional elastomers of similar hardness. This high load bearing capacity, combined with the superior abrasion and toughness is an important advantage in the dynamics of a PCP.

Polyurethane elastomers can be compounded in a wide range of hardness from 20A to 75D and can be made with resilience values as low as 2% or 75%.

Compounding is the key to creating a PU specific to its application. Polyurethane offers increased resistance to water and hydrocarbon swell as well as a lower rate of thermal expansion while maintaining its abrasion resistance, tensile strength and elongation. PUs are suitable for more applications than nitrile elastomers, which are exclusively used in down-hole PCP's today, without sacrificing mechanical integrity.

EVEN THICKNESS POLYURETHANE COATED ROTOR

Realizing that polyurethane is more compatible with a wider range of well fluids and that it has abrasion resistance and mechanical properties superior to all nitrile based compounds makes it a natural selection as the elastomeric of a PCP. Another advantage to the use of PUs is the molding process. The low viscosity of the PU at the time of molding offers the ability to form complex shapes and apply coatings in thin layers. In contrast, nitrile elastomers normally used in PCP's have relatively high viscosities and are difficult and capital intensive to injection mold in thin layers.

As mentioned earlier, one of the inherent problems with conventional PCP stators is the non-uniform elastomer thickness. In a conventional stator the elastomer is used to fill the void between the tube ID and the stator core or tooling OD forming the shape of the double helix. The elastomer layer forming the major diameter has less volume than the elastomer layer forming the minor diameter of the stator. This elastomer volume difference between the major and minor diameters allows for a significant variance in volume swell and expansion when the elastomer is subjected to higher temperature fluids such as those found in well bores. During operation in a well environment the stator actually changes geometry in relation to the fixed geometry of the rotor. What is supposed to be a meshing of two parts of the same geometry and slightly different diameters becomes a meshing of two different geometries with significant diameter differences. The end result is low efficiencies and problems with torque and vibration.

An even layer of PU or nitrile will eliminate the changing geometry issue. The swell and expansion can still occur but will be uniform resulting only in an increase in the compression fit between the rotor and stator. This change can be calculated and predetermined in the case of thermal expansion and can be anticipated in the case of fluid swell. Of course, the even layer of PU offers better compatibility and less fluid swell than most nitriles making the task of determining the resultant compression fit between the rotor and stator much simpler and more accurate.

The altered geometry under operating conditions increases and changes the compression points and adds to an already inherent problem in the thick elastomer sections of the conventional stator. As the elastomer deforms under compression and is continually flexed, heat is generated that builds up in the center section of the lobe (minor diameter). This temperature increase above the normal operating temperature of the elastomer leads to vulcanization and degradation and eventual failure. The amount and frequency of deformation determines the length of time before the elastomer fails in hysteresis. Hysteresis is a common failure of conventional stators. The even thickness PU reduces potential for hysteresis as there are no thick sections of elastomer where heat is concentrated plus the mechanical properties of the PU reduce the effects of deformation and heat generation.

It has been established that the even thickness elastomer offers increased flow performance under pressure as well as improved mechanical efficiency over the conventional non-uniform elastomer thickness. This has been substantiated in short term performance testing performed using water under controlled conditions of pressure, speed and temperature. **Fig. 3** and **Fig. 4** indicate the average performance of composite stators and PU coated rotors compared to the same length and displacement conventional rotor/stator combination. The main difference outside the materials is the compression or interference fit. The even thickness composite/PU combination has a 0.010" interference vs. the non-uniform nitrile/steel combination with a 0.020" interference fit. The pressure capability of the even thickness PU is over 2 times that of the non-uniform nitrile with half the interference fit. Extrapolation of these results to the field equates to increased mechanical efficiency (power savings) and increased operating life in the same application.

TECHNOLOGY REVERSAL AND SERVICEABILITY

The method of processing PU and the ability to bond it to almost any substrate further enhances its use. The PU can be bonded to the inside of the composite stator or it can be bonded to the rotor. In the case of down-hole PCP's there are very significant advantages gained by bonding the PU to the rotor. As mentioned earlier, a major drawback to the conventional PCP has always been the requirement for pulling tubing to retrieve the worn or failed stator. The industry is accustomed to pulling only the sucker rod string and retrieving the pump. The composite PCP design with the PU elastomer bonded to the rotor allows for retrieval of the wear element by pulling only the sucker rod string. Obviously the entire pump (in this design) cannot be retrieved by pulling the sucker rod string, but the composite stator is designed to be the long wearing element and can stay in the well. Over time there is expected to be some stator wear and the significance of this wear can be validated by the pump performance and the known dimensions of the PU coated rotor. The reversal of the wear component in this design is a factor in cost savings associated with the reduced service time.

CONCLUSIONS

The development of a composite PCP is in its early stages and to date has proven the mechanical efficiency gain of the even thickness elastomer technology over the conventional non-uniform technology. The hard long wearing stator made from composite offers a very durable corrosion resistant element that can remain in the well through several service cycles. Polyurethane offers superior abrasion resistance and mechanical properties over conventional nitrile elastomers and expands the application of PCP's due to increased compatibility with well fluids. The even thickness layer of PU bonded to the rotor puts the wear element on the sucker rod string which enhances the serviceability and reduces service time and expense. Additional data collection related to long term testing under various conditions is currently underway and comparative field test evaluations are planned.

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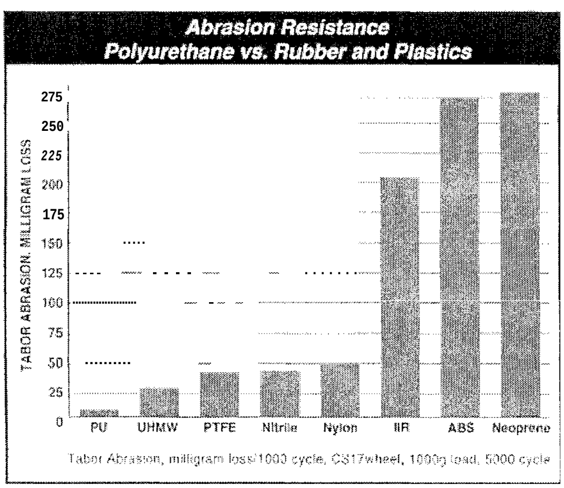


Figure 1 -Abrasion Resistance of Polyurethane vs. Rubber and Plastics

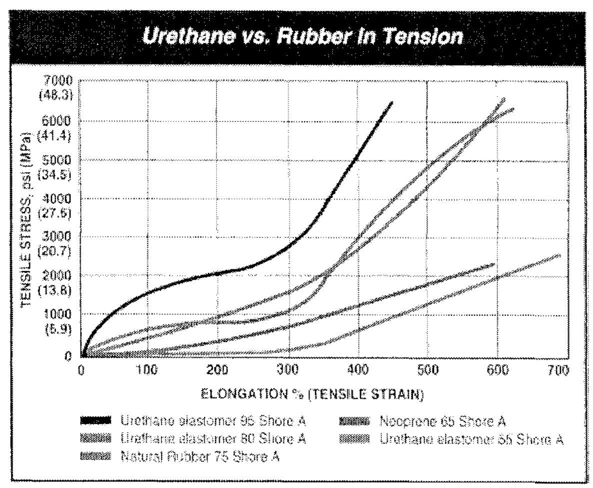
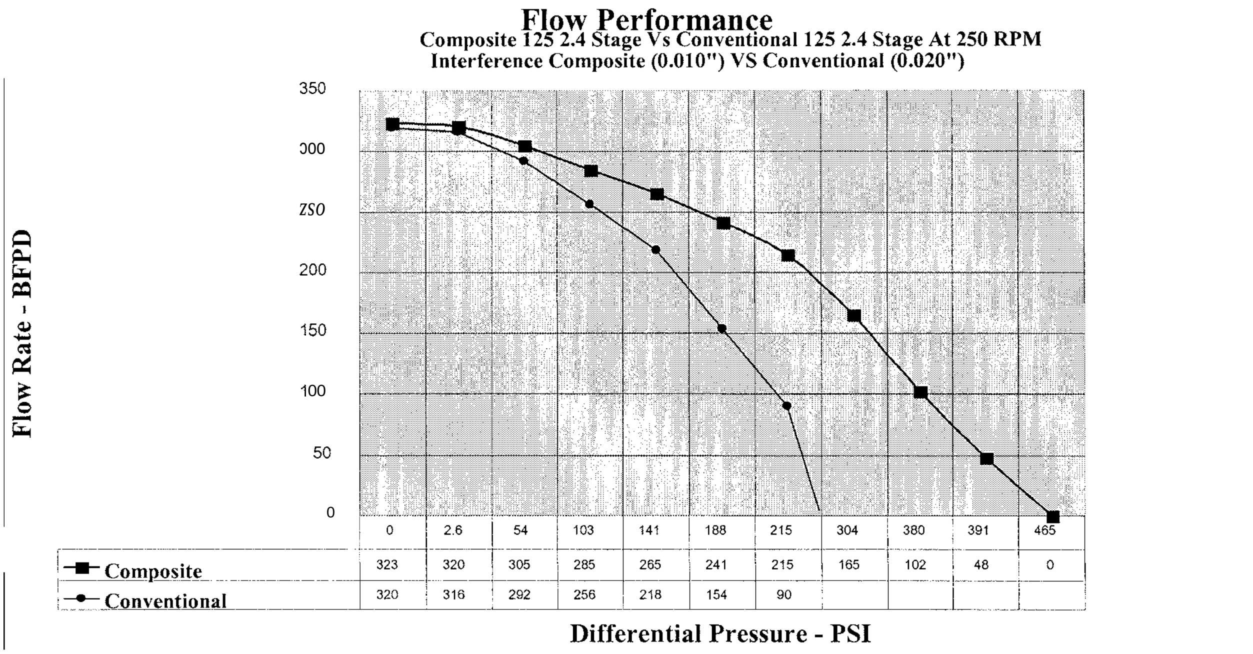
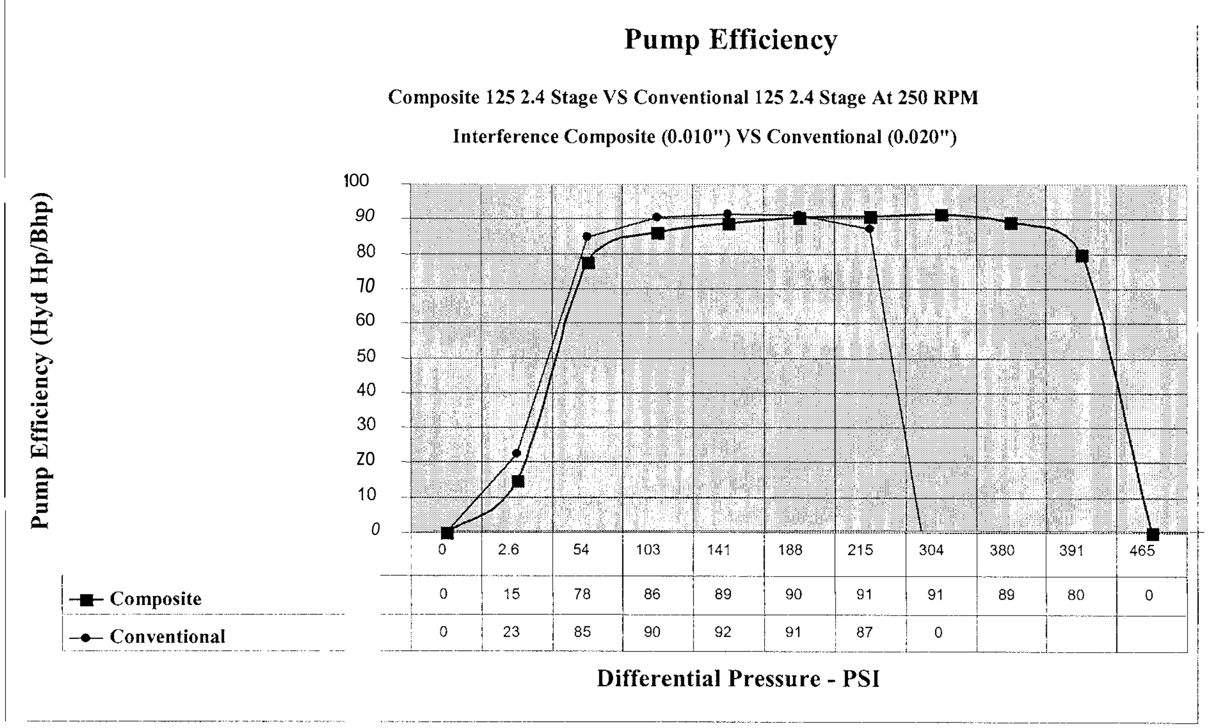


Figure 2 - Urethane vs. Rubber in Tension



	0	2.6	54	103	141	188	215	304	380	391	465
Composite	323	320	305	285	265	241	215	165	102	48	0
Conventional	320	316	292	256	218	154	90				

Figure 3 - Flow Performance Comparison-Composite vs. Conventional



	0	2.6	54	103	141	188	215	304	380	391	465
Composite	0	15	78	86	89	90	91	91	89	80	0
Conventional	0	23	85	90	92	91	87	0			

Figure 4 - Pump Efficiency Comparison Composite vs. Conventional